SeaWiFS Lunar Phase Angle Corrections

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1. Introduction

Lunar calibrations are performed one per month when the Moon is at a phase angle of approximately 7°. This phase angle is chosen to maximize the illuminated surface of the Moon while minimizing the opposition effect, i.e., the increase in brightness of sunlight diffusely reflected from a particulate surface near zero phase. Operational considerations have caused the lunar calibrations to occur over a phase angle range of $5° - 10°$. Of the 72 lunar calibrations that have occurred to date, 3 took place at phase angles of less than 6°, 3 took place at phase angles of more than 8°, and the median phase angle is 6.9°.

Two lunar phase angle corrections are required to normalize the SeaWiFS lunar observations to a phase angle of 7°. The first-order correction is a monochromatic normalization to a phase angle of 7°, while the second-order correction is an empirically-derived wavelength-dependent adjustment to the monochromatic correction. These two corrections will be disucssed in turn.

2. Monochromatic Phase Angle Correction

The change in the overall reflectance of the lunar surface with phase angle is non-Lambertian and can be approximated by Hapke's bidirectional reflectance equation. Lane and Irvine made measurements disk-integrated measurements of the Moon at wavelengths of 360–1060 nm and phase angles of $6° - 120°$. Helfenstein and Veverka used Hapke's equation and the average (in wavelength) of the measurements made by Lane and Irvine to derive a single, best-fit lunar phase function at an undefined wavelength, presumably near 500 nm. This disk-integrated phase function takes into account both the change in the reflectance of the lunar surface and the change in the illumination of the lunar surface by the sun with pahse angle. The phase function is shown in the figure *Lunar Phase Function*.

For the first-order phase angle correction, a quadratic function has been fit to the inverse of the lunar phase function over a phase angle range of $4° - 11°$ (shown in red on the plot). The fit has been normalized to yield a value of unity at a phase angle of 7° (shown in green on the plot). The correction yields values less than unity for phase angles less than 7° and greater than unity for phase angles greater than 7°. The correction has the functional form:

$$f_{4a}(\alpha) \;=\; p_0 \;+\; p_1\,\alpha \;+\; p_2\,\alpha^2 \tag{1}$$

where:

$\alpha \equiv$ phase angle
$p_0 \equiv$ constant term of the monochromatic correction
$p_1 \equiv$ linear term of the monochromatic correction
$p_2 \equiv$ quadratic term of the monochromatic correction

The monochromatic phase angle correction is shown in the figure *Monochromatic Phase Angle Correction*. The red filled circles are the six calibrations where the phase angles are less than 6° or greater than 8°.

3. Wavelength-Dependent Phase Angle Correction

The lunar calibration time series with distance corrections, partial illumination corrections, oversampling corrections, and monochromatic phase angle corrections applied are shown in figures *Band 1-4 Time Series* and *Band 5-8 Time Series*. The filled circles are calibrations where the phase angles were less than 6° or greater than 8°. Examination of these time series shows that the deviations of the measurements for the low and high phase angle calibrations vary as a function of wavelength, indicating that wavelength-dependent phase angle effects are present in the data.

Table 1. Wavelength-Dependent Phase Angle Corrections

Band	Wavelength	$p_3(\lambda)$
1	412	-0.0022298324
2	443	-0.0017558501
3	490	-0.00081116301
4	510	-0.00047827675
5	555	0.00043411166
6	670	0.0020425833
7	765	0.0031480361
8	865	0.0032304704

The second-order, wavelength-dependent phase angle corrections have been computed by fitting, for each band, a decaying exponential function of time to the calibration time series incorporating the monochromatic phase angle correction. The decaying exponential is the functional form of the time correction computed for the SeaWiFS radiometric response. The fit residuals are plotted versus phase angle in figures *Band 1-4 Phase Residuals* and *Band 5-8 Phase Residuals*. The correction coefficients are the slopes of the fit residuals regressed against phase angle. The corrections have the functional form:

$$f_{4b}(\alpha, \lambda) \;=\; 1 \;-\; p_3(\lambda)\,[\alpha \;-\; 7.0] \tag{2}$$

where:

$p_3 \quad \equiv \quad$ coefficient of the wavelength-dependent correction
$\lambda \quad \equiv \quad$ SeaWiFS band

The wavelength-dependent phase angle corrections are shown in the figure *Wavelength-Dependent Phase Angle Corrections*. The trend in the correction coefficients with wavelength, as shown in Table 1, is consistent with the monochromatic phase angle correction having an effective wavelegth of approximately 500 nm.

4. Summary

The combined monochromatic and wavelength-dependent phase angle corrections are:

$$f_4(\alpha, \lambda) \;=\; \left(p_0 \;+\; p_1\,\alpha \;+\; p_2\,\alpha^2\right)\left(1 \;-\; p_3(\lambda)\,[\alpha \;-\; 7.0]\right) \tag{3}$$